

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
05.06.2002 Bulletin 2002/23

(51) Int Cl.7: **B23H 3/00, B23H 9/10,
F04D 29/22**

(21) Application number: 01310033.4

(22) Date of filing: 30.11.2001

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR**
Designated Extension States:
AL LT LV MK RO SI

(72) Inventors:
• Battistini, Verter
50013 Campi Bisenzio, Florence (IT)
• Mariotti, Umberto
50127 Florence (IT)

(30) Priority: 30.11.2000 IT MI002595

(74) Representative: Goode, Ian Roy
**GE LONDON PATENT OPERATION,
Essex House,
12/13 Essex Street
London WC2R 3AA (GB)**

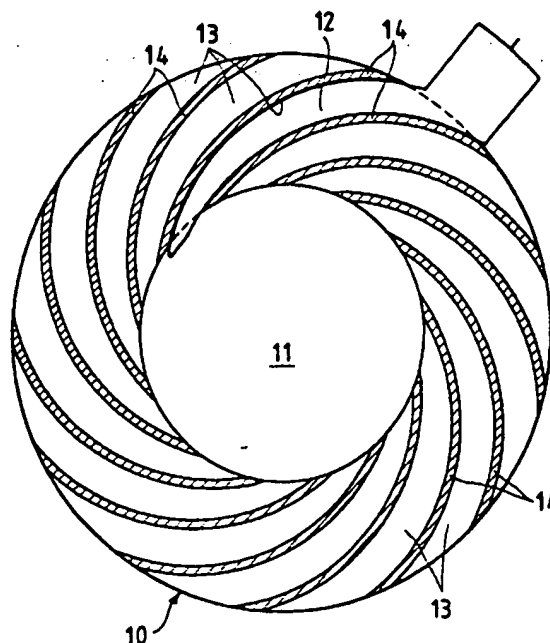
(71) Applicant: **Nuovo Pignone Holding S.P.A.
50127 Florence (IT)**

(54) **Method for production of a rotor for centrifugal compressors**

(57) A method for production of a rotor for centrifugal compressors, wherein the said rotor is produced from a monolithic disc (10), which is provided with a central hole (11). The method consists of use, within an isolating medium, of at least one first electrode (12) which has polarity opposite the polarity of the rotor, wherein the said first electrode operates starting from the outer

diameter of the monolithic disc (10), in order to produce the blades (14) and the cavities (13) of the said rotor, and wherein the processing takes place with a continuous path, consisting of a first step of roughing, followed by a second step of finishing with a tool which has a shape similar to that of the electrode used for the first, roughing step, in order to produce an accurate geometry of the blades (14).

Fig.2



Description

[0001] The present invention relates to a method for production of a rotor for centrifugal compressors.

[0002] The term centrifugal compressor normally defines a machine which restores a compressible fluid, at a pressure which is greater than that at which it received the fluid, imparting to the latter the energy necessary for the change of pressure by means of use of one or a plurality of rotors or impellers, each of which consists of a certain number of blades, which are disposed radially such as to form a certain number of passages which converge towards the centre of the rotor.

[0003] More particularly, high-pressure centrifugal compressors are normally equipped with rotors 20 which are tested in a standard manner.

[0004] It should be noted that, for a given diameter, the geometry of the rotor is fixed, and is the same for different applications, a fact which will assume particular relevance in the following description of the method according to the invention.

[0005] More particularly, the main parts of these rotors for centrifugal compressors are the hub, the shroud and the blades.

[0006] Owing to the high density of the gases, a truly critical problem in the technical field of high-pressure compressors is that of guaranteeing the stability of the rotor.

Combined forces, which are proportional to the density of the gas, and are induced by the labyrinth for the gases, can cause unacceptable sub-synchronous vibrations which have an effect on the said rotor.

[0007] In fact, the sensitivity of the rotor to these forces increases more or less in proportion with the flexibility of the rotor.

[0008] In addition, the entire dynamic behaviour of the rotor is particularly critical for this type of application, and the simplest means for increasing the rigidity of the rotor in the same operative conditions (same bearings, same temperature, same pressure of the gas, etc) is that of using shafts which have large diameters.

[0009] The diameters both of the shafts and of the hubs have thus been increased in the known art, such as to increase the lack of sensitivity to external disturbances, and therefore to improve the characteristic rotodynamic behaviour of high-pressure centrifugal compressors.

[0010] The spacers have thus been eliminated, and the aerodynamic path is obtained directly on the shaft.

[0011] More specifically, two rings, the front one of which is in two pieces, and the rear one which is in a single piece, maintain the axial position, whereas a coating with a high level of hardness protects the shaft.

[0012] These characteristics assure that the aerodynamic path does not change, and ensure that this configuration is particularly efficient in increasing the rigidity of the shaft, however, these changes mean that a different technology must be taken into consideration for pro-

duction of these rotors for centrifugal compressors.

[0013] With particular reference to the known art, it should be noted that the blades are conventionally obtained by means of milling the hub (or shroud), and subsequently the welding is carried out from the interior of the aperture, in order to join the parts.

[0014] Another technique is used for rotors with a low flow coefficient, in which the blades are too thin to make it possible to carry out the welding from the interior.

10 [0015] In fact, in this technique, the two parts are slot-welded from the rear of the hub (the blades are machined on the shroud), owing to the presence of the nose or front portion of the shroud, which has the same diameter as the main end of the blade.

15 [0016] After the welding has been carried out, the heat treatment is also carried out, which, as will be appreciated, reduces the residual tensions which have formed.

20 [0017] Each rotor is separated from the others by a spacer, in order to create the necessary aerodynamic space at the intake of the rotor.

[0018] Thus, on these bases, it is apparent that it becomes very difficult to increase the diameter of the hub, and thus the diameter of the slot-welding, from the exterior.

25 [0019] The object of the present invention is thus to provide a method for production of a rotor for centrifugal compressors, such that the above-described requirements are fulfilled.

30 [0020] Another object of the present invention is to provide a method for production of a rotor for centrifugal compressors, which makes it possible to obtain a very high level of dimensional accuracy, which is in line with the required expectations.

35 [0021] Another object of the present invention is to provide a method for production of a rotor for centrifugal compressors, which provides the possibility of obtaining a high level of structural resistance of the rotor.

40 [0022] A further object of the present invention is to provide a method for production of a rotor for centrifugal compressors, which makes it possible to obtain a high level of dimensional accuracy, as well as an optimum surface quality of the finished product.

45 [0023] These objectives and others according to the invention are achieved by a method for production of a rotor for centrifugal compressors, wherein the said rotor is produced from a monolithic disc, provided with a central hole, characterised in that it consists of use, within an isolating medium, of at least one first electrode which has polarity opposite that of the polarity of the said rotor, wherein the said first electrode operates starting from the outer diameter of the said monolithic disc, in order to produce the blades and the cavities of the said rotor, and wherein this processing takes place with a continuous path, consisting of a first step of roughing, followed by a second step of finishing with a tool which has a shape similar to that of the electrode used for the first, roughing step, in order to produce an accurate geometry of the said blades.

[0024] According to one embodiment, the method according to the invention includes a further step of finishing, in which an electrode operates on the surfaces of the blades, at the inner portion of the said rotor, in order to round the main ends of the said blades, on the inner side of the disc.

[0025] As an alternative, according to a preferred variant of the method according to the invention, an electrode 15 carries out at least the first step of roughing according to the method, wherein the said electrode is shaped such as to be able to produce the profile of each of the blades, both on the pressure side and on the suction side.

[0026] In fact, this electrode has a first and a second portion, which are separated from one another by the space which is necessary for the presence of a blade.

[0027] Further characteristics of the method for production of a rotor, according to the present invention, are defined in the other claims attached to the present application.

[0028] The characteristics and advantages of the method for production of a rotor for centrifugal compressors, according to the present invention, will become more apparent from the following description of a typical embodiment, provided by way of non-limiting example, with reference to the attached schematic drawings, in which:

- Figure 1 represents an electrode for electroerosion, which acts on a rotor which is destined for a centrifugal compressor, according to the method of the invention, in a first operative position of erosion;
- Figure 2 represents the electrode for electroerosion in figure 1, which acts on the rotor of the compressor, in a second operative position;
- Figure 3 represents a second electrode for electroerosion, which acts on the rotor in figure 1, in another operative position;
- Figure 4 represents a third electrode for electroerosion, which acts on the inner part of the rotor in figure 1, in yet another operative position; and
- Figure 5 represents a fourth electrode for electroerosion, which acts on the inner part of the rotor in figure 1, in yet another operative position.

[0029] With particular reference to the figures in question, the method according to the invention will now be described, on the understanding that the method of electroerosion has finally been selected from amongst the different processing methods.

[0030] In fact, it is understood that, in the processing operations for electroerosion, two metal parts are immersed in an isolating liquid, and are connected to a source of electrical energy.

[0031] When the power is switched on, an electric voltage is created between the two metal parts.

[0032] If the two parts are taken together to the correct distance, the electric voltage is discharged, and an elec-

tric spark passes through the distance between the two parts.

[0033] At the point at which this spark strikes, the metal is heated to the extent that it melts.

5 [0034] After application of a large number of these sparks, which are emitted one after another (and never simultaneously), it is possible to produce gradually the required shape in the piece of metal, according to the shape of the electrode.

10 [0035] A few hundred thousand of these sparks must be produced every second, before the erosion takes place.

15 [0036] The results are highly variable, depending on the intensity, frequency, duration, length and polarity of the discharges.

[0037] There are two different methods for electroerosion, which are known technically by the names of die-sinking EDM, and wire-cut EDM, where EDM stands for Electrical Discharge Machining.

20 [0038] In both the aforementioned electroerosion methods, the electrical energy of the electrical supply source is transformed, according to the results required, by means of controlled pulse generators of a type with highly developed technology.

25 [0039] The EDM process usually takes place in an isolating liquid, which is continually regenerated and filtered, such as to remove all the metal residues.

30 [0040] By this means, the external conditions remain unchanged during the entire process, even if this lasts for hours or days.

[0041] The possibilities provided by the present devices are enormous, i.e high speed of cutting and removal, extremely efficient automatic operations, interconnection and storage of recurrent and very lengthy processing cycles, and virtually 100% monitoring of the final shape and of the metal surfaces which are processed, from perfectly smooth to extremely rough. Owing to these special properties, EDM is considered as a technology with great future prospects.

40 [0042] In the case of die-sinking EDM technology, the shape required is formed negatively in the metal, with a three-dimensional electrode.

[0043] By means of superimposition of the movements on the three main axes x, y and z, the most varied shapes, indentations and cavities can be created, in a manner which cannot be obtained by means of any other processing system.

45 [0044] For example, it is possible to produce a helical cavity or a rectangular hole in a single block of steel, or a very thin, hardened metal sheet which cannot be subjected to mechanical pressure, can be processed.

50 [0045] In the case of the wire-cut EDM process, the shape required is stored in the computer, and is conveyed in the form of codes which can be understood by the machine, which subsequently cuts the shape independently, guiding the wire along the path.

[0046] In the case of complicated shapes which required cuts, or angled, conical or other unusual surfac-

es, the upper and lower wire guiding systems perform the different movements depending on the cases.

[0047] With reference now in greater detail to the description of the method for production of the centrifugal compressor rotor, the following comments are made.

[0048] As shown clearly in figure 1, the starting point is a monolithic disc 10, made of steel which is perforated centrally by the hole 11, in order to produce the radial compressor rotors by means of electroerosion.

[0049] More particularly, according to the method of the present invention, numerically controlled machines are preferably used.

[0050] The tools for the method and the rotor itself are electrodes with opposite polarity, and the isolating means are normally oil or specific fluid with a high level of resistivity.

[0051] Two different types of tools are used in order to produce the rotor.

[0052] A first electrode, indicated by the reference number 12, is able to produce the blades 14 and the cavities 13 of the rotor, starting from the outer diameter of the disc 10.

[0053] The first electrode 12 has the same shape as the aperture itself of the cavity 13, and moves as illustrated in figures 1-2, in which the initial position and the final position can be seen.

[0054] The final result of this first step is also shown in figure 2, where the parts of material left between the erosions of the electrode 12 are the outer surfaces, which are still rough, of the rotor blades 14.

[0055] Since it is a planar object, the electrode 12 must also move in an axial direction.

[0056] The processing with a continuous path begins with general erosion, which is followed by a step of finishing with a specific tool, the shape of which is similar to the electrode 12, but which makes it possible to produce accurate geometry of the blades 14.

[0057] When the electrode 12 completes its work, the blades 14 on the inner side of the disc 10 have a flat main end.

[0058] It is therefore necessary to carry out the processing illustrated in figures 4-5, where another electrode 16 operates on the surfaces 17 and 18 of the blades 14, as well as to use a further electrode 19 which can operate on the surface 20.

[0059] Alternatively, an electrode 15 which has the particular shape represented in figure 3 can carry out the roughing step of the electroerosion method.

[0060] In fact, owing to its own particular shape, this electrode 15 produces the profile of the blade 14, both on the pressure side and on the suction side.

[0061] More particularly, the electrode 15 has a first and a second portion 15', 15'', which are separated from one another by the space necessary for the presence of a blade 14.

[0062] The following description makes apparent the characteristics and advantages of the method according

to the present invention, for production of a rotor for centrifugal compressors.

[0063] The following concluding points and observations are now made, such as to define the said advantages more clearly and accurately.

[0064] Firstly, by means of use of the method according to the invention, it is possible to increase the diameter of the hub of the rotor.

[0065] In addition to the possibility of increasing the diameter of the hub of the rotor, the main advantages of use of electroerosion are firstly the lack of structural discontinuity.

[0066] Another important advantage is provided by the possibility of obtaining a high level of structural resistance, as well as of obtaining a high level of dimensional accuracy, and finally an optimum surface quality of the finished product.

[0067] All these points are particularly important when rotors which are designed for machines with re-injection at high pressure are produced.

[0068] In fact, owing to the high pressure and high density involved, the pressure pulses which originate from the asymmetry of the aerodynamic field, particularly in the phase known as discharge scroll, can give rise to significant periodic forces.

[0069] However, in this context, it can be appreciated that the method according to the invention makes it possible to avoid any metallurgical discontinuity inside the rotor, a fact which clearly represents a significant technological step forward.

[0070] In terms of dimensional accuracy, the centrifugal compressors in question are normally characterised by a very low flow coefficient.

[0071] From a geometric point of view, this results in very thin aerodynamic passages, sometimes of approximately 0.3 - 0.4".

[0072] The distortion which is associated with the processing known as slot welding can modify the width of the blade by 5% or more, for these rotors which have a low flow level.

[0073] On the other hand, by means of spark erosion or electroerosion according to the method described, the accuracy which can be obtained is 1-2%, a fact which permits a more accurate match between the performance levels expected and those obtained.

[0074] Finally, it is apparent that many other variations can be made to the method for production of a rotor for centrifugal compressors, which is the subject of the present invention, and that, in the practical application of the invention, any materials, dimensions and forms can be used according to requirements, and can be replaced by others which are technically equivalent.

55 Claims

1. Method for production of a rotor for centrifugal compressors, wherein the said rotor is produced from a

monolithic disc (10), which is provided with a central hole (11), **characterised in that** it consists of use, within an isolating medium, of at least one first electrode which has polarity opposite the polarity of the said rotor, wherein the said first electrode operates starting from the outer diameter of the said monolithic disc (10), in order to produce the blades (14) and the cavities (13) of the said rotor, and wherein the processing takes place with a continuous path, consisting of a first step of roughing, followed by a second step of finishing with a tool which has a shape similar to that of the electrode used for the said first, roughing step, in order to produce an accurate geometry of the blades (14).

2. Method according to claim 1, **characterised in that** it includes a further step of finishing, in which an electrode (16, 19) operates on the surfaces (17, 18, 20) of the said blades (14), at the inner portion of the said rotor, in order to round the main ends of the said blades (14), on the inner side of the said disc (10).
3. Method according to claim 1, **characterised in that** an electrode (15) carries out at least the said first step of roughing according to the method, wherein the said electrode (15) is shaped such that the said electrode (15) can produce the profile of each of the said blades (14), both on the pressure side and on the suction side.
4. Method according to claim 3, **characterised in that** the said electrode (15) has a first and a second portion (15', 15''), wherein the said first and second portions (15', 15'') are separated by the space which is necessary for the presence of a blade (14).
5. Method according to claim 1, **characterised in that** the said first electrode (12) has substantially the same shape as the aperture itself of the cavity (13), and moves along a curve which is defined by points, and can be assimilated to an arc of circumference.
6. Method according to claim 1, **characterised in that** the said method for production is an electroerosion method of the die-sinking EDM type, in which the said method takes place in an isolating fluid, wherein the said isolating fluid is continually regenerated and filtered such as to remove all the metal residues.
7. Method according to claim 6, **characterised in that** the shape required is formed negatively in the metal of the said disc (10), with a three-dimensional electrode, wherein, by means of superimposition of the movements on the three main axes x, y and z, the most varied shapes, indentations and cavities required can be created, including toric surfaces in-

side the shroud aperture.

8. Method according to claim 1, **characterised in that** the said method is an electroerosion method of the wire-cut EDM type, wherein the shape required is stored in the memory of a computer, and is conveyed in the form of codes which can be understood by the machine, which subsequently cuts the shape independently, guiding the electrode along the processing path.
9. Method according to one or more of the preceding claims, **characterised in that** the said isolating means used are oil or specific fluid with a high level of resistivity.
10. Method according to one or more of the preceding claims, **characterised in that** it is implemented by means of numerically controlled machines.

Fig.1

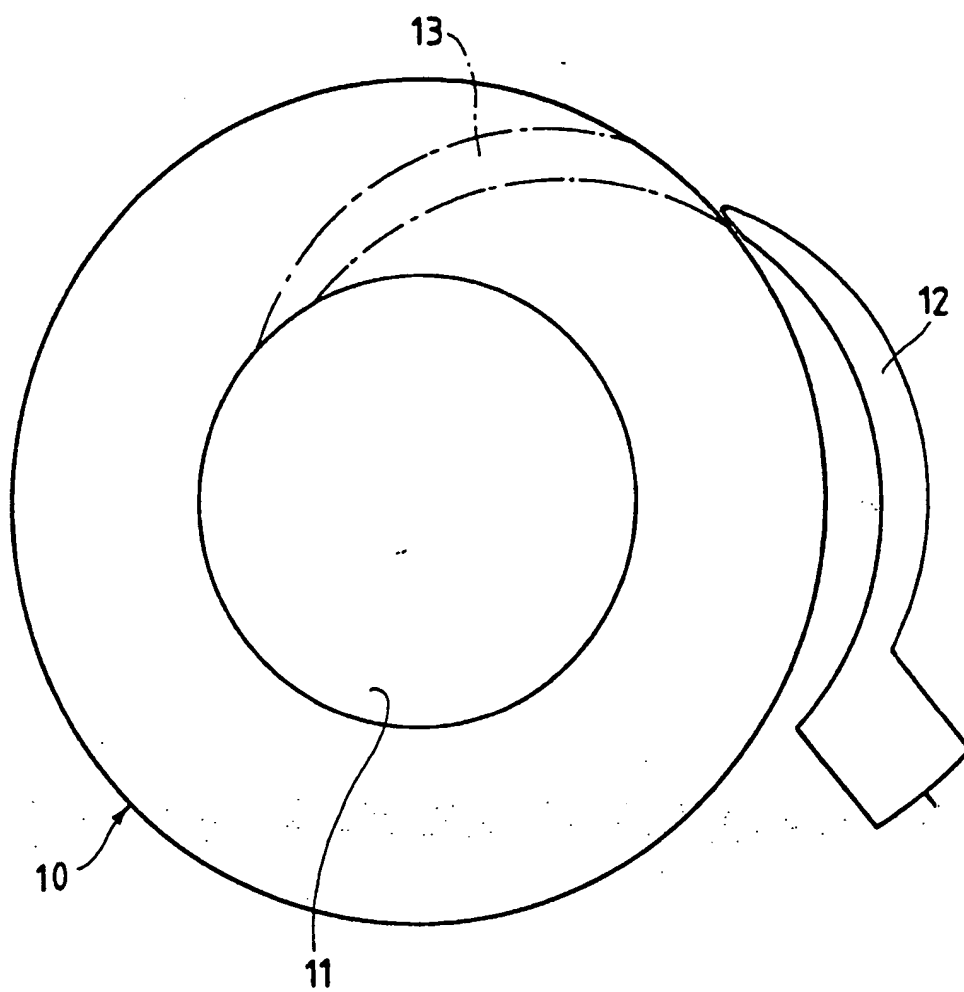


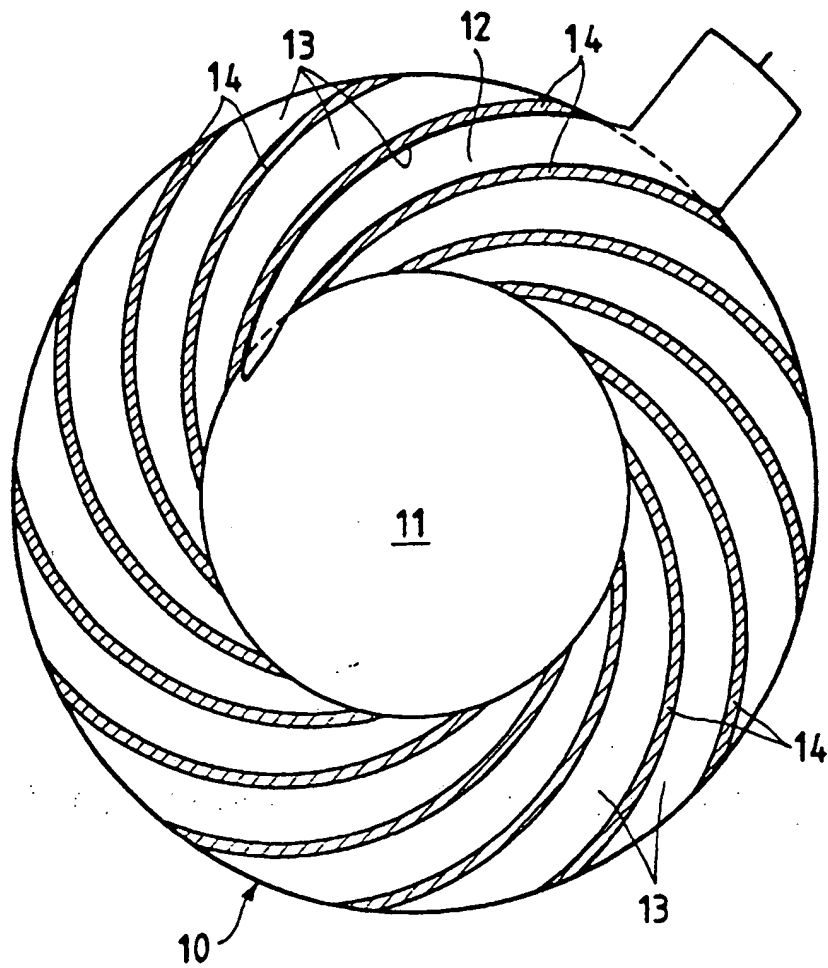
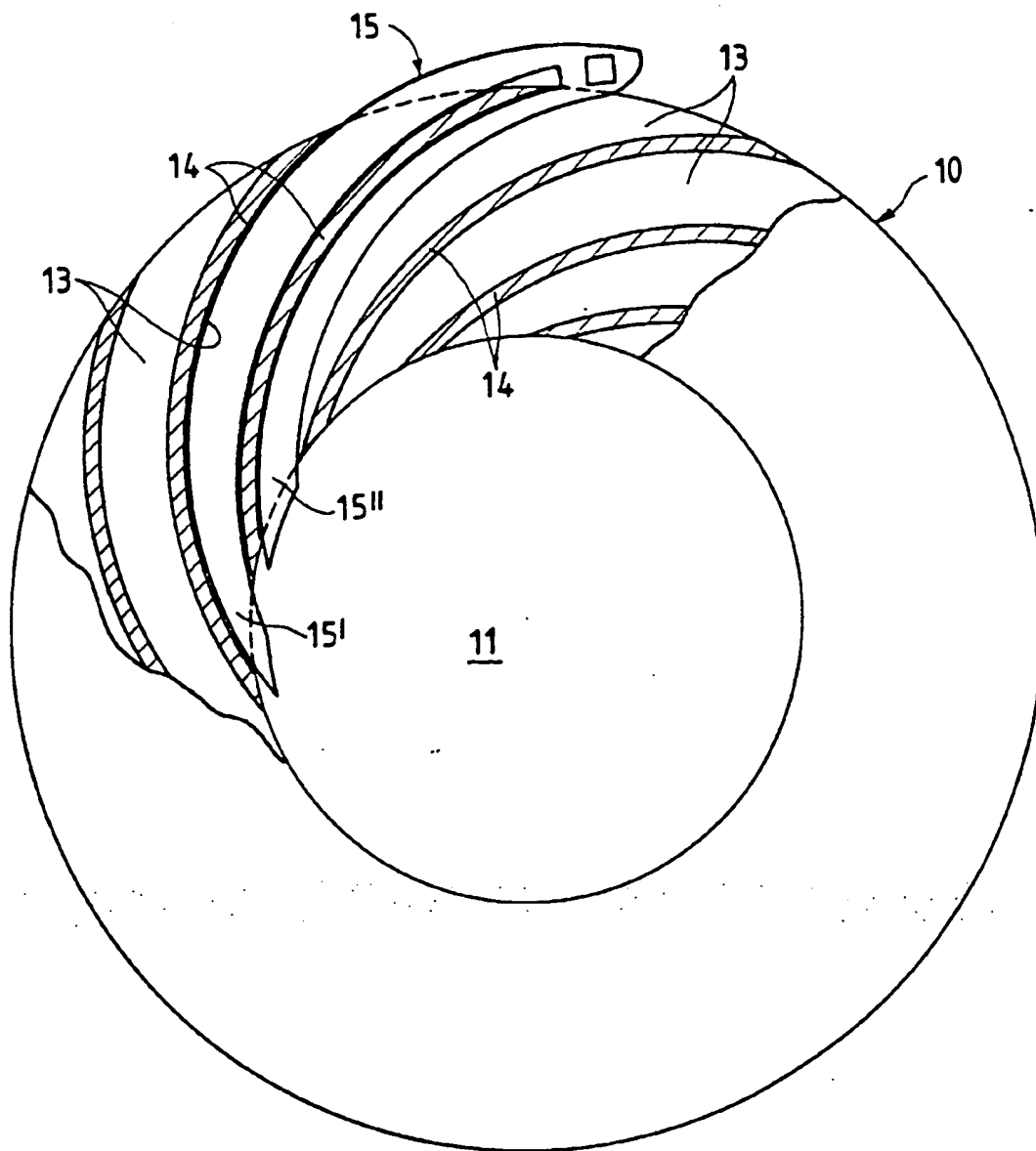
Fig.2

Fig.3

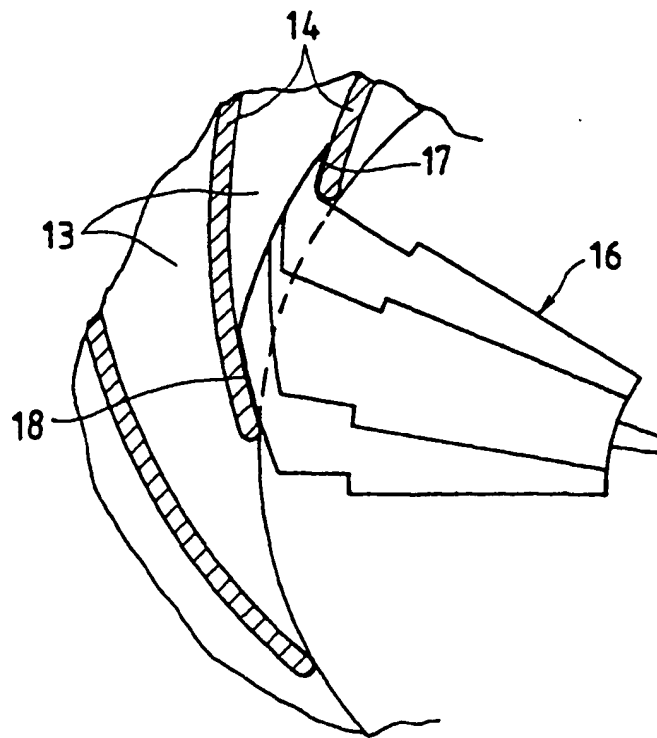


Fig.4

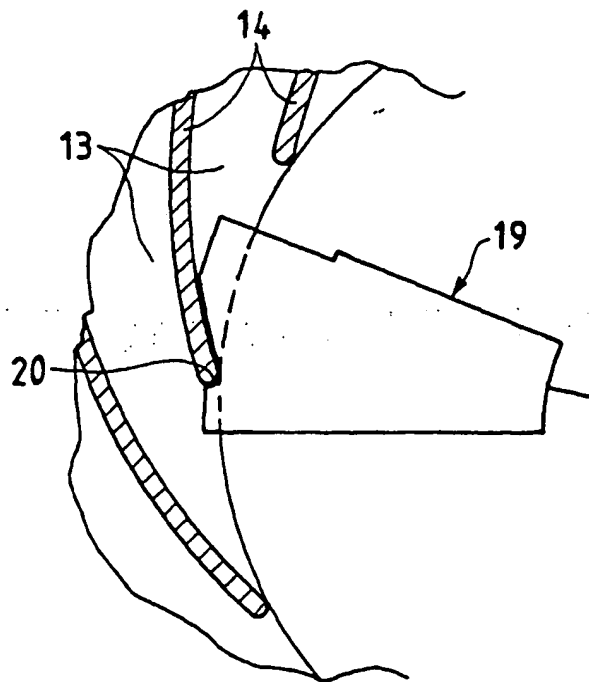


Fig.5



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 31 0033

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	PATENT ABSTRACTS OF JAPAN vol. 013, no. 542 (M-901), 5 December 1989 (1989-12-05) & JP 01 222820 A (KOKU KIKAKU KOGYO KK), 6 September 1989 (1989-09-06) * abstract *	1-5	B23H3/00 B23H9/10 F04D29/22
X	FR 2 570 970 A (MEON FILS ETS) 4 April 1986 (1986-04-04)	1-5	
Y	* figures 1-11 *	6-10	
X	US 3 288 699 A (CROSS JACK A ET AL) 29 November 1966 (1966-11-29)	1	
Y	* column 1, line 9-17; figures 1-8 *	6-10	
X	NL 7 203 180 A (KONINKLIJKE MACHINEFABRIEK STORK N.V.) 12 September 1973 (1973-09-12) * figures 1-14 *	1-5	
A	EP 0 426 233 A (VARIAN SPA) 8 May 1991 (1991-05-08) * abstract *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	CH 502 511 A (SIEMENS AG) 31 January 1971 (1971-01-31) * claim 1 *	1	B23H F04D
Y	US 3 372 099 A (CLIFFORD JOHN E) 5 March 1968 (1968-03-05) * column 1, line 9 - column 2, line 54 *	6-10	
Y	EP 0 495 985 A (SODICK CO LTD) 29 July 1992 (1992-07-29) * column 3, line 30 - column 4, line 48 *	6-10	
A	US 4 891 485 A (BRIFFOD JEAN-PAUL) 2 January 1990 (1990-01-02) * abstract *	6,8	
-/-			
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 14 March 2002	Examiner Fistas, N
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>& : member of the same patent family, corresponding document</p>			



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 31 0033

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 1 774 279 A (LOCHMAN EMIL R) 26 August 1930 (1930-08-26) * page 1, left-hand column, line 1 - page 2, right-hand column, line 114 * -----	6	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 14 March 2002	Examiner Fistas, N
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 01 31 0033

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

14-03-2002

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
JP 01222820	A	06-09-1989	JP 2075490 C	25-07-1996
			JP 7096166 B	18-10-1995
FR 2570970	A	04-04-1986	FR 2570970 A1	04-04-1986
			CH 666209 A5	15-07-1988
			DE 3533957 A1	10-04-1986
US 3288699	A	29-11-1966	DE 1540723 A1	22-01-1970
			GB 1062343 A	22-03-1967
NL 7203180	A	12-09-1973	NONE	
EP 0426233	A	08-05-1991	IT 1238201 B	09-07-1993
			AT 85923 T	15-03-1993
			DE 69000968 D1	01-04-1993
			DE 69000968 T2	09-06-1993
			EP 0426233 A1	08-05-1991
			HK 1000008 A1	03-10-1997
			JP 2021020 C	19-02-1996
			JP 3184726 A	12-08-1991
			JP 7055409 B	14-06-1995
			US 5188514 A	23-02-1993
CH 502511	A	31-01-1971	NONE	
US 3372099	A	05-03-1968	BE 647107 A	17-08-1964
			CH 431753 A	15-03-1967
			DE 1515195 A1	23-12-1971
			FR 1396638 A	23-04-1965
			GB 1044224 A	28-09-1966
			NL 6404893 A	02-11-1964
EP 0495985	A	29-07-1992	JP 2939310 B2	25-08-1999
			JP 4101722 A	03-04-1992
			DE 69113434 D1	02-11-1995
			DE 69113434 T2	28-03-1996
			EP 0495985 A1	29-07-1992
			HK 60196 A	12-04-1996
			WO 9203246 A1	05-03-1992
			US 5359169 A	25-10-1994
US 4891485	A	02-01-1990	EP 0295206 A1	14-12-1988
			JP 1121132 A	12-05-1989
			JP 2532582 B2	11-09-1996
			KR 9209122 B1	13-10-1992

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 01 31 0033

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

14-03-2002

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 1774279	A	26-08-1930	NONE